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INVERTEBRATE FAUNA OF WASTEWATER PONDS IN SOUTHEASTERN IDAHO

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ABSTRACT.—Water column invertebrates were sampled with 3.8-L activity traps in 15 sewage, industrial, and radioactive wastewater ponds at the Idaho National Engineering Laboratory in southeastern Idaho. One collection was made per pond, per month, during all months the ponds were ice-free from June 1990 through July 1991. In addition, nutrient and selected heavy metal concentrations in pond water were determined in July 1991. Arsenic, barium, boron, lead, selenium, and mercury were detected in ponds. Sewage ponds generally had higher nitrogen and phosphorus levels than industrial and radioactive ponds. Of the 30 aquatic invertebrate taxa collected, the most ubiquitous were Rotifera, Daphnidae, Eucopepoda, Ostracoda, Acari, Baetidae, Corixidae, Notonectidae, Dytiscidae, and Chironomidae. Activity trap samples from sewage ponds contained more Rotifera, Daphnidae, and Notonectidae, whereas industrial ponds yielded more Chydoridae, Acari, and Baetidae. Numbers of Oligochaeta, Eucopepoda, Ostracoda, Corixidae, Dytiscidae, and Chironomidae collected were not significantly different between sewage and industrial ponds. Compared with natural systems, these ponds had fewer taxa, but a greater number of individuals of most taxa. The high number of invertebrates collected is attributed to the lack of fish in wastewater ponds and the high levels of nitrogen and phosphorus, particularly in sewage ponds.

Key words: aquatic invertebrates, sanitary wastewater, industrial wastewater, Idaho National Engineering Laboratory.

Constructed ponds have been a common tool in wastewater treatment for decades (Gloyna et al. 1976). Wastewater ponds are constructed in a variety of manners and used in various treatment procedures, from settling ponds to ponds with various aquatic macrophytes that enhance removal of nutrients and break down organic materials (Brix 1993). Recently, constructed wetlands have also been incorporated into many wastewater treatment systems associated with municipalities and industry (Task Force on Natural Systems 1990, Moshiri 1993). Wastewater ponds and wetlands are also associated with federal research sites such as the Idaho National Engineering Laboratory (INEL) in southeastern Idaho and the Hanford Site in south central Washington.

Wastewater ponds at INEL receive sanitary, industrial, and radioactive waste produced at the facility. Other than wildlife watering cisterns and ephemeral rain pools, waste disposal ponds are usually the only surface water at INEL and, as such, attract wildlife (Halford and Millard 1978, Howe and Flake 1989, Millard et al. 1990, Cieminski 1993). Migrating and resident waterfowl, shorebirds, blackbirds, and swallows use the ponds heavily, feeding partially or exclusively on aquatic invertebrates, and on invertebrates that have emerged from the ponds (Millard et al. 1990, Cieminski 1993).

Most studies of macroinvertebrates, especially insects, in conjunction with waste treatment have been limited to studies of benthic invertebrate assemblages in streams receiving raw sewage or effluent from sewage treatment plants (e.g., Klotz 1977, Kownacki 1977, Duda et al. 1982, Kondratieff and Simmons 1982, Kondratieff et al. 1984, Chadwick et al. 1986, Lewis 1986, Crawford et al. 1992). Literature on plankton and nekton in constructed ponds focuses mainly on pathogens, and microscopic flora and fauna important in waste decomposition, such as bacteria, protozoa, and algae (Goulden 1976, Task Force on Natural Systems 1990).

Because the invertebrate fauna of wastewater ponds attracts wildlife, it is important to understand invertebrate communities of the ponds, as well as if and how they differ from natural communities. Our objectives were to (1) provide baseline data on invertebrate

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resources available to migrating birds in constructed waste ponds and (2) determine if nutrients and selected heavy metals in ponds influence invertebrate populations.

STUDY SITE

The 231,600-ha INEL lies in Butte, Bonneville, Bingham, Clark, and Jefferson counties, ID, on the western edge of the Snake River plain near the foothills of the Lost River, Lemhi, and Bitterroot mountain ranges (Fig. 1). Topography at INEL is flat to rolling, with elevation ranging from 1463 m to 1829 m.

Big Lost River, Little Lost River, and Birch Creek drainages terminate in playas on or near INEL; flow is intermittent and largely diverted for agriculture. During this study no surface water flowed onto INEL. Plant communities are dominated by big sagebrush (*Artemisia tridentata*), low sagebrush (*A. arbuscula*), and three-tipped sagebrush (*A. tripartita*) (McBride et al. 1978).

INEL lies in a semiarid, cold desert. Annual temperatures range from −42°C to 39°C. Average annual precipitation is 19.1 cm, 40% of which falls from April through June (Clawson et al. 1989). Precipitation levels are lowest in July. Snowfall averages 71.3 cm per year, and snow cover can persist from December through March.

Wastewater ponds on INEL contained sanitary waste (eight ponds), industrial waste (four ponds), or radioactive waste (three ponds) (Fig. 1). Because two radioactive ponds also contained industrial waste, in most analyses radioactive ponds were grouped with industrial ponds (as "industrial ponds") for comparison with sewage ponds.

Ponds were grouped around INEL facilities, which were 4–36 km apart. Generally, each facility had between one and four sewage ponds and an industrial waste pond. Sewage ponds ranged from 0.04 to 2.20 ha and were 0.6–2 m deep. Industrial waste ponds ranged from 0.20 to 2.24 ha and were 0.3–4.5 m deep. Seven of the sewage ponds and one industrial pond were lined to prevent infiltration into surrounding soil. Four ponds (all industrial and/or radioactive) supported emergent plant growth. A more thorough description of the ponds can be found in Cieminski (1993).

METHODS

Water samples were collected at ponds in July 1991 and analyzed for nutrients (nitrogen and phosphorus) and selected heavy metals (arsenic, barium, beryllium, boron, lead, selenium, and mercury) that could influence presence of invertebrates. Water pH was taken once at each pond at the same time water samples were collected. Further heavy metal and nutrient sampling was prohibitively expensive and time consuming. Water samples were analyzed at the U.S. Geological Survey's National Water Quality Laboratory at Arvada, CO. Collection and analysis methods were as per Brown et al. (1970) and Fishman and Friedman (1989). Data on heavy metals for pond ANLi (acronyms and names of pools are included in Tables 1 and 5) were taken from analyses conducted in 1988.

Benthic samples were not taken because most ponds had lined bottoms, or because sediment sampling was not permitted for other reasons. We collected water column invertebrates once each month to obtain gross estimates of invertebrate populations. Additional collections and identification were time- and cost-prohibitive, given our concurrent collection of bird and mammal count data at these ponds for a related project. Nevertheless, we felt that invertebrates influenced bird use of ponds, thus the need for estimates of invertebrate abundance.

Water column invertebrates were collected at all nonradioactive ponds in months the ponds were ice-free from June 1990 through May 1991. Because of restricted access to radioactive waste ponds, they were sampled only once during July 1991. Invertebrates were collected in 3.8-L activity traps (Ross and Murkin 1989) suspended horizontally 5.3 cm under the water surface for approximately 24 h. Modifications on the technique of Ross and Murkin (1989) were necessary since most ponds had artificial liners; therefore, jars could not be suspended from a pipe driven in the pond bottom. Instead, jars were suspended from floats and attached to a 50- to 300-cm-long piece of PVC pipe anchored on the pond's shore. The first sample was taken at the southeast corner of each pond. Subsequent monthly sample locations were chosen randomly based on a single-digit number of paces

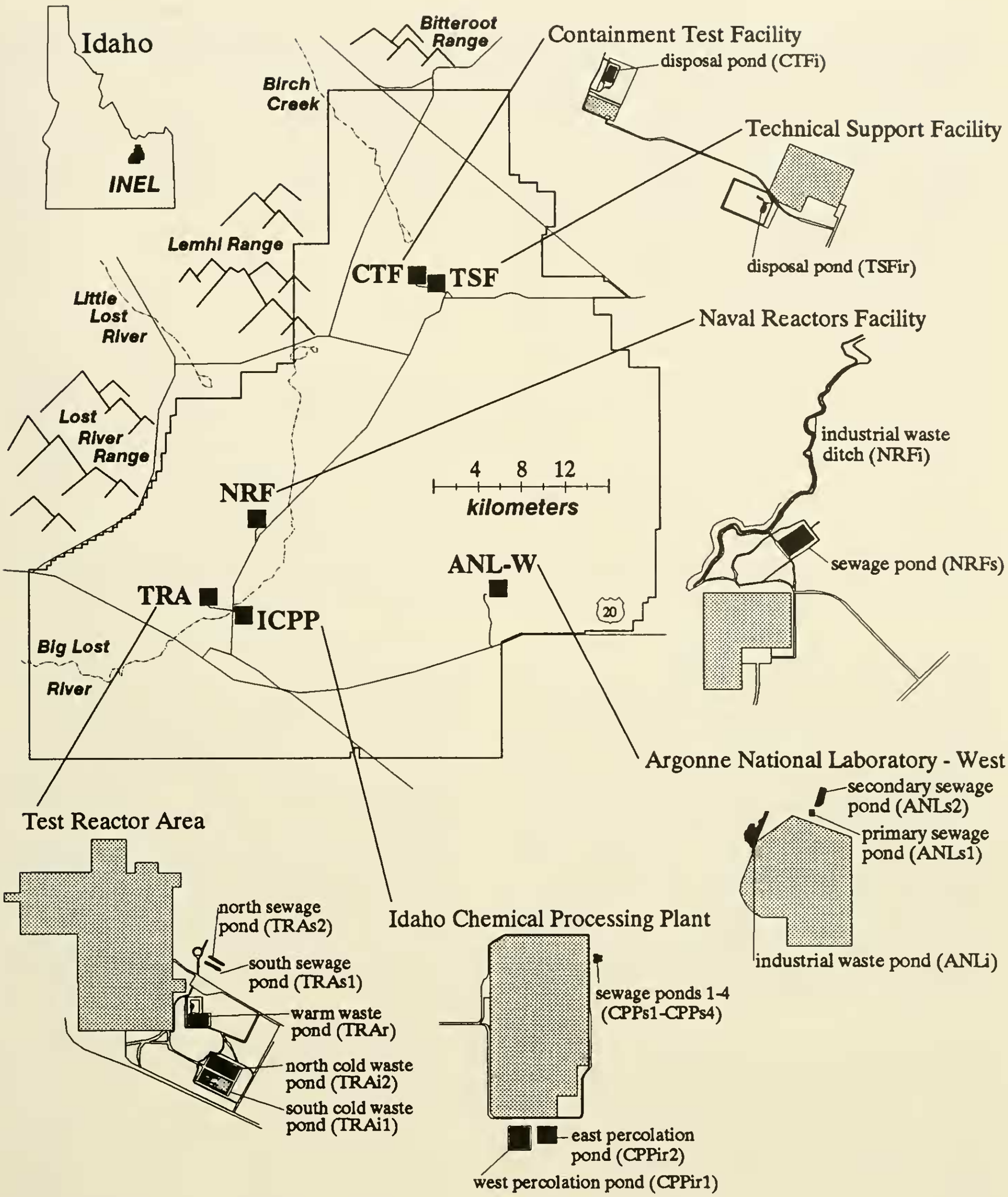

Fig. 1. Map of the Idaho National Engineering Laboratory, indicating location of facilities and wastewater ponds where invertebrate fauna was sampled. Waste type is indicated by lowercase letter in the pond code: s = sewage, i = industrial, r = radioactive.

counterclockwise from the previous sample site. Where dense emergent vegetation covered the near-shore zone, the activity trap was placed in the nearest open water.

Activity trap contents were strained through a 75-μm (No. 200) sieve and preserved in 80% propanol. In the laboratory, macroinvertebrates were removed first. Samples from shallow ponds with unlined bottoms often contained sediment. To these, rose bengal stain was added to aid in sorting microinvertebrates (Mason and Yevich 1967). Samples in which zooplankton was estimated to exceed 300 individuals were subsampled. To subsample, samples were diluted to 500 or 1000 ml and stirred while 1% of the volume was drawn out with 1- and 2-ml Henson-Stemple pipettes.

Invertebrate fauna were counted and identified to family, with the exception of the orders Oligochaeta, Acari, Araneae, Eucopepoda, Ostracoda, and Lepidoptera, and the phyla Nematoda and Rotifera. Invertebrates were identified using keys in Pennak (1989) for non-insects, Merritt and Cummins (1984) for aquatic insects, and Borror and DeLong (1971) for terrestrial insects. B. McDaniel (Plant Science Department, South Dakota State University, Brookings) identified terrestrial invertebrate families and verified other identifications.

Because data were not normally distributed, nonparametric analysis methods were used. A median test was conducted on the dozen most common invertebrate taxa to determine if their abundance in sewage ponds differed from that in industrial ponds. For each taxa, numbers of individuals collected in each sample were used in analysis. Data were pooled over all ponds, years, and months within each of the two groups: sewage ponds and industrial ponds. Pooling samples for years and ponds allowed ample sample size for comparison of gross invertebrate population differences between pond types. A median test was also run on the total number of species collected per pond during the entire sampling period to determine if species richness was greater at sewage ponds or industrial ponds. A third median test was conducted to compare invertebrate numbers between ponds with heavy metal concentrations greater than EPA criteria and those with heavy metal concentrations within EPA chronic exposure standards. Data were again pooled over all ponds, years, and months. Radioactive waste ponds were eliminated from median tests because only one sample was taken from them.

RESULTS

Water Chemistry

Heavy metal concentrations in most ponds were below criteria established by the EPA (U.S. Environmental Protection Agency 1987) (Table 1). Mercury was the only metal found in concentrations that might affect aquatic life (ponds TRAr and NRFi). However, in TRAr and NRFi mercury concentration was below the acute value of 2.4 μg/L (U.S. Environmental Protection Agency 1987).

Sewage ponds had higher nitrogen and phosphorus concentrations than industrial and radioactive ponds (Table 2). Ammonia (NH_4–N) concentrations in most ponds were within the range found in unpolluted surface water (Wetzel 1983); however, NH_4–N concentrations at ICPP sewage ponds were well above those usually found in eutrophic lakes. Nitrite (NO_2–N) concentrations indicated high organic pollution at all sewage ponds except NRFs, which was the only sewage pond where NO_2–N concentrations did not exceed those of industrial and radioactive

TABLE 1. Selected heavy metal concentrations (μg/L) in wastewater ponds at INEL, Idaho, August 1991, and EPA criteria[a].

	Pond[b]							Criteria
Metal	ANLi[c]	CPPir2	TRAr	TRAi1	NRFi	CTFi	TSFir	(μg/L)
Arsenic	9.4	2	<1[d]	<1	3	5	2	190[e]
Barium	71	<100	<100	<100	<100	<100	100	50,000
Beryllium	<5	<10	<10	<10	<10	<10	<10	5.3
Boron	—	30	50	70	120	90	10	5000
Lead	<2.1	3	3	3	2	3	2	3.2[f]
Selenium	<2	1	<1	1	2	1	1	35
Mercury	<20	<0.1	0.2	<0.1	1.4	<0.1	<0.1	0.012[g]

[a]Concentrations at or below these levels should have no adverse effects on freshwater systems. Naval Reactor Facilities officials suggested the following clarification: "The criteria in the last column have questionable applicability to the NRFi. The EPA maximum contaminant level for mercury in public community drinking water systems is 2.0 μg/L."

[b]ANLi = Argonne National Laboratory–west industrial waste pond, CPPir2 = Idaho Chemical Processing Plant east percolation pond (industrial and radioactive), TRAr = Test Reactor Area warm waste pond (radioactive), TRAi1 = Test Reactor Area south cold waste pond (industrial), NRFi = Naval Reactors Facility industrial waste ditch, CTFi = Containment Test Facility disposal pond (industrial), TSFir = Technical Support Facility disposal pond (industrial and radioactive).

[c]ANLi water sample tested at Envirodyne Engineers, St. Louis, MO, February 1988.

[d]< symbol means water sample contained less than the detection level, which follows the < symbol.

[e]Arsenic (III)

[f]At water hardness of 100 mg/L. Value is 1.3 at water hardness of 50 mg/L.

[g]Mercury (II)

TABLE 2. Nutrient concentrations in wastewater ponds at INEL, Idaho, August 1991.[a]

		Nitrogen (mg/L as N)					Phosphorus (mg/L as P)
Pond	pH[b]	NH_4^+	NO_2^-	$NO_2^-+NO_3$	NO_3	$NO_3:NH_4^+$	PO_4^{-3}
Sewage ponds							
ANLs2	9.02	0.19	0.17	0.46	0.29	1.50	1.20
CPPs1	7.52	11.00	2.20	4.60	2.40	0.21	4.00
CPPs2	7.23	17.00	0.69	2.40	1.71	0.10	4.80
CPPs3	7.33	17.00	0.15	0.46	0.31	0.02	6.40
CPPs4	7.43	17.00	0.14	0.43	0.29	0.02	6.10
TRAs	6.87	0.41	0.13	5.10	4.97	12.12	0.79
NRFs	9.90	0.40	0.02	0.14	0.12	0.30	3.00
Nonsewage ponds							
ANLi	7.42	0.97	0.09	0.74	0.65	0.67	1.40
CPPir2	8.80	0.04	0.05	1.30	1.25	30.49	0.01
TRAi1	7.60	0.01	0.06	1.10	1.04	104.00	0.07
TRAr	8.43	0.15	0.01	0.27	0.26	1.73	0.01
NRFi	7.42	0.01	0.01	1.60	1.59	159.00	0.40
CTFir	9.97	0.01	0.01	0.45	0.44	44.00	0.09
TSFir	9.75	0.04	0.02	0.11	0.09	2.17	0.12

[a]Samples were collected between 0800 and 1400 h, Mountain Standard Time.
[b]Water pH values fluctuate readily. According to the INEL Industrial Waste Management Information System, 1989 effluent pH ranges and numbers of months pH was sampled ( ) were as follows: ANLs1, 7.8–9.8 (7); CPPs1–4, 7.5–8.6 (12); TRAs1–2, 7.1–8.0 (10); NRFs, 7.4–11.0 (12); TRAi1–2, 7.5–8.0 (6); TRAr 6.3–6.8 (2); NRFi, 6.9–7.5 (12); TSFir, 7.1–7.9 (12).

ponds. Nitrate (NO_3–N) concentrations were not noticeably different between sewage ponds and industrial/radioactive ponds, and NO_3–N levels of all ponds were within ranges commonly found in unpolluted freshwater (Wetzel 1983).

The NO_3–N:NH_4–N ratio is an indication of organic pollution, a lower number indicating greater pollution (Wetzel 1983). The NO_3–N:NH_4–N ratio was <1 at all sewage ponds except ANLs2 and TRAs, and >1 at all industrial and radioactive ponds except ANLi. However, only in ICPP sewage ponds were ratios small enough to be considered organically contaminated (Wetzel 1983). Phosphorus concentrations at most sewage ponds were much higher than the concentration in the highest industrial/radioactive pond. Compared with maximums in uncontaminated surface waters, phosphorus concentrations in sewage ponds were 4–30 times greater, but of the industrial and radioactive ponds only concentrations in ANLi and NRFi were substantially greater (7 and 2X) (Wetzel 1983).

Invertebrate Fauna

Forty-nine taxa of invertebrates were collected from waste ponds, of which 30 were aquatic (Table 3). Most nonaquatic forms were found in small numbers. Collembola, however, were found regularly and were probably on the water surface or shaken from emergent vegetation in the collection process. In order of decreasing abundance, the main taxa collected were Rotifera, Daphnidae, Ostracoda, Eucopepoda, Chydoridae, Corixidae, Chironomidae, Oligochaeta, Baetidae, Psychodidae, Acari, Dytiscidae, and Notonectidae. The above taxa were also the most ubiquitous, except Chydoridae, Oligochaeta, and Psychodidae, which were found in large numbers but in few samples.

The number of invertebrate taxa collected per pond ranged from 5 to 22. Excluding terrestrial taxa, the number of aquatic taxa collected ranged from 4 to 16 per pond. Radioactive ponds were sampled only in July, but the number of taxa collected was almost identical to July samples from nonradioactive industrial ponds (Table 4). Statistical analyses were not performed on radioactive ponds because only one activity trap sample was collected. Industrial (ANLi, TRAi1 and 2, NRFi, and CTFi) and sewage ponds had similar (P = .11) numbers of taxa per sample.

Within most taxa, the number of individuals collected varied greatly from pond to pond (Table 5). A median test revealed that activity trap samples from sewage ponds contained more Rotifera (P < .01), Daphnidae (P < .01), and Notonectidae (P = .04), whereas industrial ponds yielded more Chydoridae (P < .01),

TABLE 3. Invertebrate taxa and mean number collected from 15 wastewater ponds at INEL, Idaho, 1990–91[a].

Taxa	$\bar{x}$/24 h (n = 96)
Phylum Rotifera	1471.14
Phylum Nematoda	0.05
Phylum Annelida	
Class Oligochaeta (aquatic earthworms)	6.32
Class Hirudinea (leeches)	
Order Rhynchobdellida	
Family Glossiphoniidae	0.02
Phylum Arthropoda	
Class Crustacea	
Order Cladocera (water fleas)	
Family Daphnidae	1351.26
Family Chydoridae	102.88
Family Sididae	0.09
Order Eucopepoda (copepods)	151.45
Order Ostracoda (seed shrimps)	317.17
Order Amphipoda (scuds)	
Family Talitridae	0.45
Class Arachnoidea	
Order Acari (mites)	1.51
Order Araneae (spiders)[b]	0.04
Class Insecta	
Order Collembola (springtails)	
Family Entomobryidae[b]	0.57
Family Onychiuridae[b]	0.30
Order Ephemeroptera (mayflies)	
Family Baetidae	5.71
Family Caenidae	0.01
Order Odonata	
Suborder Anisoptera (dragonflies)	
Family Aeshnidae	0.01
Suborder Zygoptera (damselflies)	
Family Coenagrionidae	0.31
Order Thysanoptera (thrips)[b]	
Family Thripidae (common thrips)[b]	0.11
Family Aeolothripidae (banded thrips)[b]	0.02
Order Hemiptera (true bugs)	
Family Corixidae (water boatmen)	39.76
Family Notonectidae (backswimmers)	0.53
Order Homoptera	
Family Aphidae (aphids)[b]	0.05
Family Cercopidae (spittlebugs)[b]	0.01
Family Cicadellidae (leafhoppers)[b]	0.03
Family unidentified[b]	0.25
Order Coleoptera (beetles)	
Family Chrysomelidae (leaf beetles)	0.03
Family Coccinellidae (ladybird beetles)[b]	0.01
Family Dytiscidae (predaceous diving beetles)	0.65
Family Elmidae (riffle beetles)	0.01
Family Gyrinidae (whirligig beetles)	0.01
Family Haliplidae (crawling water beetles)	0.02
Family Hydrophilidae (water scavenger beetles)	0.02
Family Ptiliidae (feather-winged beetles)	0.01
Family Staphylinidae (rove beetles)	0.02
Order Trichoptera (caddisflies)	
Family Leptoceridae	0.05
Order Lepidoptera (butterflies and moths)[b]	0.02
Order Diptera (flies)	
Family Ceratopogonidae (biting midges)	0.01
Family Psychodidae (moth flies and sand flies)	1.68
Family Chironomidae (midges)	11.52
Family Tipulidae (crane flies)	0.02
Family unidentified, adults[b]	0.80
Family unidentified, pupae	0.99
Order Hymenoptera	
Family Formicidae (ants)[b]	0.03
Family Platygasteridae[b]	0.01
Family Braconidae[b]	0.01
Family Encyrtidae[b]	0.01
Family Pteromalidae[b]	0.01
Family Scelionidae[b]	0.01
Family Sphecidae (sphecid wasps)[b]	0.01

[a]Invertebrates were collected in 3.8-L activity traps suspended in the water column for 24 h, one per pond, per month. Collections were June–October 1990 and March–May 1991 for 12 ponds, and July 1991 for 3 radioactive ponds.
[b]Individuals found were mostly or exclusively terrestrial.

Acari (P = .01), and Baetidae (P = .01). Numbers of Oligochaeta (P = .44), Eucopepoda (P = .50), Ostracoda (P = .09), Corixidae (P = .08), Dytiscidae (P = .54), and Chironomidae (P = .70) collected were not significantly different between sewage and industrial ponds.

Invertebrate numbers in pond NRFi, which had a high mercury content, were compared to those in the remaining industrial ponds, where mercury was not detected. Samples from NRFi contained more Chironomidae (P = .02) and Oligochaeta ($P < .01$), and fewer Chydoridae (P = .03) and Ostracoda (P = .03) than ponds ANLi, TRAi, and CTFi. Numbers of Rotifera (P = .10), Daphnidae (P = .10), Eucopepoda (P = .10), Acari (P = .15), Baetidae (P = .55), Corixidae (P = .07), Notonectidae (P = .45), and Dytiscidae (P = .07) were similar between the pond with mercury and those without.

DISCUSSION

Wastewater ponds at INEL were nutrient-rich, especially sewage ponds. Organic enrichment may be the cause of high abundance and low number of invertebrate taxa found. Species richness at sewage ponds was similar to that at industrial ponds. However, species composition differed between sewage and industrial ponds. Differences were probably due to the greater organic enrichment in sewage ponds.

Activity trap samples from INEL ponds contained fewer invertebrate taxa than comparable samples from natural waters (Gordon et al.

TABLE 4. Number of aquatic invertebrates per collection (activity trap set for 24 h) from radioactive waste ponds at INEL, Idaho, July 1991[a].

Taxa	CPPir2[b] (*n* = 1)	TRAr (*n* = 1)	TSFir (*n* = 1)
Daphnidae	94	1	59
Chydoridae	0	0	129
Eucopepoda	35	0	818
Ostracoda	5	0	1620
Amphipoda	0	0	1
Baetidae	2	0	0
Corixidae	1	5	0
Dytiscidae	0	6	4
Chironomidae	7	0	18

[a]Data from radioactive waste ponds were not analyzed with those from sewage and industrial ponds because only one sample was taken from radioactive ponds.
[b]CPPir2 = Idaho Chemical Processing Plant east percolation pond (industrial and radioactive), TRAr = Test Reactor Area warm waste pond (radioactive), TSFir = Technical Support Facility disposal pond (industrial and radioactive).

1990, Neckles et al. 1990). Dominant taxa collected from study ponds were similar to dominant taxa collected in activity traps at natural wetlands in Nebraska (Gordon et al. 1990) and Manitoba (Neckles et al. 1990), with the exception of Culicidae, Turbellaria (Neckles 1990), and Gastropoda (Gordon et al. 1990, Neckles et al. 1990), which were not collected from wastewater ponds. In our study fewer taxa per sample were collected compared to activity trap samples from seasonal wetlands (Cowardin et al. 1979, Neckles et al. 1990); seasonal wetlands, like organically enriched systems of sewage ponds, tend to have low invertebrate taxa diversity (Wiggins et al. 1980).

The reduced number of taxa in wastewater ponds may be due to lack of emergent vegetation in most ponds. Odonate families Libellulidae and Lestidae, which were collected by Gordon et al. (1990) but not from wastewater ponds, are commonly associated with vascular hydrophytes (Merritt and Cummins 1984). Vegetation has been found to be correlated with macroinvertebrate species richness (Gilinsky 1984).

Another possible cause of low species richness in wastewater ponds is high organic waste content. Streams and wetlands receiving organic waste typically exhibit low invertebrate taxa diversity (Olive and Dambach 1973, Brightman and Fox 1976, Kondratieff and Simmons 1982, Kondratieff et al. 1984, Victor and Dickson 1985, Pearson and Penridge 1987). Hilsenhoff (1988) assigned arthropod families from streams in the Great Lakes region a tolerance value from 0 (lowest tolerance to organic pollution) to 10 (highest). Eleven of the families for which Hilsenhoff (1988) presented tolerance values were found in INEL ponds, and only 2 had tolerance values of less than 4. Those 11 families and tolerance values are as follows: Aeshnidae and Tipulidae (3), Baetidae, Elmidae, and Leptoceridae (4), Ceratopogonidae (6), Caenidae (7), Chironomidae and Talitridae (8), Coenagrionidae (9), and Psychodidae (10). The two families with a 3 tolerance rating were represented by only single specimens in INEL wastewater ponds.

Low invertebrate diversity in industrial ponds may be caused by organic or chemical constituents. Although nutrients in industrial waste ponds were within ranges found in natural waters, most industrial ponds at INEL would be considered eutrophic (Wetzel 1983). Additional organic enrichment in sewage ponds did not affect species richness compared to industrial ponds; however, species composition (%) was different between the two pond types. Metal and saline pollution has also been found to decrease aquatic invertebrate diversity (Savage and Rabe 1973, Seagle et al. 1980, Euliss 1989).

In most instances, the seven heavy metals tested did not occur in concentrations great enough to affect aquatic life. Only mercury was found at concentrations over chronic exposure levels. At concentrations below chronic levels, freshwater organisms should show no chronic toxic effects (U.S. Environmental Protection Agency 1987). Chydoridae and Ostracoda were scarcer, and Chironomidae and Oligochaeta more abundant, in samples from pond NRFi, wherein mercury was detected. Other toxins may occur in the water, and no other ponds with elevated mercury concentrations were available for comparison. Therefore, we do not know if mercury caused the difference detected.

Although species richness of INEL ponds was low, comparison with natural wetlands (Gordon et al. 1990, Neckles et al. 1990) revealed that study ponds exhibited high invertebrate abundance. Of the taxa that wastewater pond and Nebraska wetland collections had in common, wastewater pond samples contained higher densities of all except Gyrinidae, Ceratopogonidae, and Hirudinea (Gordon et al. 1990). Gyrinidae and Ceratopogonidae were collected in almost identical amounts, and Hirudinea were more abundant in Nebraska

TABLE 5. Median and maximum ( )[a] number of aquatic invertebrates per collection (activity trap set for 24 h) from sewage and industrial waste ponds at INEL, Idaho, 1980–1991. The 12 most abundant taxa are presented.

	Sewage ponds[b]								Industrial ponds			
Taxa	ANLs1 ($n = 8$)[c]	ANLs2 ($n = 7$)	CPPs1 ($n = 8$)	CPPs2 ($n = 8$)	CPPs3 ($n = 8$)	CPPs4 ($n = 8$)	TRAs ($n = 6$)	NRFs ($n = 8$)	ANLi ($n = 8$)	TRAi ($n = 6$)	NRFi ($n = 8$)	CTFi ($n = 8$)
Rotifera	0(47282)	0(15)	2.5(6300)	0(4300)	0(1350)	161(5350)	131.5(1700)	0(36150)	0(0)	0(0)	0(60)	0(0)[d]
Daphnidae	80(142)	8331(28302)	861.5(9428)	656(3324)	874(4799)	236.5(5800)	35.5(1824)	79(523)	282(8770)	0(3)	32.5(95)	18(253)[d]
Notonectidae	0(2)	0(7)	0(0)	0(0)	1.5(10)	0.5(4)	0(0)	0(7)	0(1)	0(0)	0(1)	0(0)[d]
Oligochaeta	0(0)	0(0)	0(1)	0(0)	0(0)	0(0)	1(300)	0(0)	0(0)	0(0)	0.5(187)	0(0)[e]
Eucopepoda	0(2)	0(5)	378.5(1794)	32.5(549)	20(631)	46.5(1218)	112.5(700)	0(3)	57(455)	0(2)	0.5(105)	347(947)[e]
Ostracoda	0(3)	0(107)	58.5(5376)	10.5(100)	2.5(562)	0(16)	12(700)	0(1)	120(711)	152(441)	0(6)	8.5(16900)[e]
Corixidae	1(49)	68(314)	0.5(26)	2.5(8)	15(800)	30(450)	2.5(50)	21(118)	2.5(35)	0(0)	0(0)	2.5(51)[e]
Dytiscidae	0(4)	0(3)	0(4)	0(0)	1(4)	0(1)	0.5(2)	0(1)	0(7)	0(1)	0(0)	0(2)[e]
Chironomidae	0(3)	1(7)	1(150)	2(6)	4.5(12)	2(11)	0.5(248)	1(19)	0(3)	0(0)	4(27)	1(240)[e]
Chydoridae	0(0)	0(0)	0(700)	0(0)	0(0)	0(0)	0(0)	0(0)	1(1950)	0(0)	0(0)	212(3734)[f]
Acari	0(1)	0(1)	0(0)	0(1)	0(0)	0(0)	0.5(1)	0(1)	0(4)	0(0)	0(2)	8.5(73)[f]
Baetidae	0(1)	0(1)	0(50)	0(3)	0(14)	0(0)	1(97)	0(0)	1.5(14)	0(0)	0(25)	18(167)[f]

[a]Means are not given because data are nonparametric. Minimums were >0 in only six instances and >6 twice.
[b]ANLs1 and ANLs2 = Argonne National Laboratory—west sewage ponds, CPPs1-4 = Idaho Chemical Processing Plant sewage ponds, TRAs = Test Reactor Area sewage ponds (TRAs1 and TRAs2 contained water alternately), NRFs = Naval Reactors Facility sewage pond, ANLi = Argonne National Laboratory—west industrial waste pond, TRAi = Test Reactor Area north and south cold waste ponds (industrial—contained water alternately), NRFi = Naval Reactors Facility industrial waste ditch, CTFi = Containment Test Facility disposal pond (industrial).
[c]Samples were collected once per month: ANLs1, CPPs1-4, NRFs, ANLi, NRFi, and CTFi, June–October 1990 and March–May 1991. ANLs2, June–October 1990 and April–May 1991; TRAs, August–October 1990 and March–May 1991. TRAi, July–September 1990 and March–May 1991.
[d]Median test shows numbers collected from sewage ponds are higher ($P \leq .05$) than numbers collected from industrial ponds.
[e]Median test shows numbers collected from sewage ponds are not different ($P > .05$) from numbers collected from industrial ponds.
[f]Median test shows numbers collected from sewage ponds are lower ($P \leq .05$) than numbers collected from industrial ponds.

wetlands, compared to our study ponds (Gordon et al. 1990). Also, in our study, more Cladocera and Ostracoda were collected compared to activity trap samples from seasonal wetlands (Neckles et al. 1990), which tend to have a high invertebrate abundance (Wiggins et al. 1980). Nutrient-polluted natural waters also have invertebrate communities containing many individuals of a few species (Brightman and Fox 1976, Lubini-Ferlin 1986); Brightman and Fox (1976) attribute this partially to a reduction in competition from pollution-intolerant forms.

High invertebrate growth and abundance have been associated with high algal productivity (Wallace and Merritt 1980, Richardson 1984), which in turn has been associated with high phosphorus and nitrogen concentrations (Liao and Lean 1978, Wetzel 1983). Most INEL wastewater ponds were eutrophic or highly eutrophic (Wetzel 1983). Therefore, wastewater ponds, which are higher in nutrients than natural wetlands, would be expected to produce more invertebrate biomass.

The absence of fish in study ponds probably also contributed to high invertebrate densities. Fish have been shown to decrease aquatic invertebrate densities (Gilinsky 1984). For most taxa, collections from industrial ponds also had more individuals than collections from natural systems (Gordon et al. 1990, Neckles et al. 1990), even though industrial ponds were not as nutrient-rich as sewage ponds.

In certain systems a large abundance of invertebrates has also been attributed to a paucity of insect predators (Brightman and Fox 1976, Williams 1985, Dodson 1987). However, several predaceous taxa were collected from waste ponds, most notably Dytiscidae and Notonectidae. Because these taxa were collected in greater numbers from wastewater ponds than from natural wetlands (Gordon et al. 1990), and because Notonectidae were most numerous in sewage ponds where many prey taxa were also most numerous, we surmise the large number of invertebrates collected from waste ponds resulted mostly from a reduction in competition from pollution-intolerant taxa, high algal productivity, and the absence of fish, rather than from lack of invertebrate predation.

Comparison of our results on water column invertebrates with other studies of sewage ponds is limited due to a scarcity of published papers. Porcella et al. (1972) noted large populations of *Daphnia* in a reservoir fed mostly by treated sanitary wastewater. Daphnidae, Rotifera, and Notonectidae were more common in INEL sewage ponds than in industrial ponds. All three species, as well as Oligochaeta, Eucopepoda, Ostracoda, and Corixidae (Sinclair 1975), are common inhabitants of sanitary wastewater. Oligochaeta, Eucopepoda, Ostracoda, Corixidae, and Chironomidae were abundant in sewage ponds, but not more so than in industrial ponds. Cladocera, Eucopepoda, Ostracoda, Corixidae, and Chironomidae were also common in evaporation ponds in California, which contain salts and heavy metals (Euliss et al. 1991).

Invertebrate communities in INEL sewage ponds differed from those in organically polluted streams. However, in making these comparisons we note that our sampling methods did not target benthic organisms. In nutrient-enriched stream reaches, oligochaetes and chironomids are dominant (Duda et al. 1982, Pearson and Penridge 1987, Crawford et al. 1992), but we found no difference in numbers between sewage and industrial ponds. Some chironomid species (Kownacki 1977) and oligochaete families (Lewis 1986) are characteristic of clean waters, and it is possible the species inhabiting sewage ponds differed from those in industrial ponds. Ostracoda have also been described as pollution tolerant (Kownacki 1977), but we found no difference in their numbers at the .05 level of significance; at the .10 level, sewage pond samples contained more ostracods. Baetidae may be either pollution tolerant (Savage and Rabe 1973, Victor and Dickson 1985) or intolerant (Kownacki 1977) depending upon the species. We found more Baetidae in industrial ponds, indicating they, as well as Chydoridae and Acari which were also more abundant in industrial pond samples, may be less tolerant of low oxygen concentrations than the other common taxa.

Taxa found in greater abundance in sewage ponds than in industrial ponds were those that could take advantage of the unique and difficult living conditions. Eutrophic waters typically exhibit lower dissolved oxygen concentrations and greater fluctuations in dissolved oxygen and pH than less organically enriched waters. Some cladoceran species can form hemoglobin when dissolved oxygen concentrations are low; thus, oxygen levels are rarely a limiting factor (Pennak 1989). The same is true of rotifers; certain genera are capable of withstanding anaerobic conditions for a short time and very low oxygen concentrations for extended periods (Pennak 1989). Since Notonectidae breathe at the water surface (Merritt and Cummins 1984), they are unaffected by dissolved oxygen concentrations. Most Cladocera are less affected by pH fluctuations than some taxa because they typically occur over a wide pH range (Pennak 1989). If pH levels are too high or too low, Cladocera and Rotifera can withstand temporarily unfavorable environmental situations by producing resting eggs that are resistant to adverse chemical conditions. Under more favorable conditions, Cladocera and Rotifera life cycles allow them to respond quickly to improving conditions (Pennak 1989).

Regarding the feeding habits of taxa that were more abundant in sewage ponds, Notonectidae were possibly taking advantage of the reduced competition from other predators. Both rotifers and *Daphnia* are omnivorous and feed on any suitable-sized food particle; therefore food was abundant for them in sewage ponds (Sinclair 1975). *Daphnia* can alter their body structure in response to algal concentrations, which is thought to be a mechanism for surviving algal blooms (Pennak 1989). Thus, while conditions in sewage ponds are hostile to many species, those that can tolerate the conditions flourish due to an abundant food supply and the absence of fish.

In summary, wastewater ponds had low invertebrate diversity, which we attribute to lack of vegetation and inability of many species to withstand the environmental conditions. Wastewater ponds also had high invertebrate abundance, which we attribute to reduction of competing taxa, organic enrichment, and absence of vertebrate predators. There was no indication that heavy metal concentrations were high enough to reduce water column invertebrate concentrations in most ponds.

High invertebrate concentrations in INEL wastewater ponds provided an abundant food source for many bird species, migratory and resident, which used INEL wastewater ponds. Bacteria, protozoa, and algae are important in waste treatment because they reduce the organic load of wastewater and convert waste into a form useable by organisms in the receiving water body (Goulden 1976). In systems like some at INEL where water loss is through evaporation, all waste processing occurs in the pond. Zooplankton are also important in waste elimination and transfer (Goulden 1976, Patrick 1976, Bogatova and Yerofeyeva 1980). Other aquatic invertebrates that consume algae or bacteria, or feed on zooplankton, and are then eaten by birds also influence the reduction and transformation of organic waste and its dissipation out of the system.

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